"Design of Energy Management Model for Renewable Energy Based Hybrid Power System"

SHORT SYNOPSIS

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It is a bonafide record of original work carried out under the supervision of Dr. Anita Khosla and has not been submitted in full or part to any other university or institute for degree or diploma. Further, it is certified that short synopsis is plagiarism free and proof has been submitted.

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Abstract

With the construction and maintenance of a grid becoming uneconomical and relatively unreliable, distributed power generation is gaining popularity. Considering the transmission cost involved in centralized generation and the use of fossil fuels, distributed generation comes out to be a solution. Distributed generation increases the reliability, flexibility, upgradability, economy of scale, diversity and efficiency of power system.

Fuel cell is one of the most reliable and efficient renewable source of energy. Different fuels are used to operate different types of fuel cells and the byproduct left after electricity generation is also environment friendly. Fuel cells are capable of electrifying remote locations as well as mobile units.

Solar based power generation ie. photovoltaics (PV) provides a lot of advantages but suffer from one major drawback of the intermittent solar availability which can change the system frequency. So a fuel cell is also installed with the solar PV units which can compensate for the changes in generation and the load variation.

Due to continuous variations in the load there is a variation in the system frequency. With the involvement of renewable energy, the continuous availability of input becomes an issue and hence load frequency control and the use of storage devices in the power system becomes important. Initially conventional proportional integral derivative controllers were used for frequency stabilization. The parameters of these controllers were optimized using advanced optimization techniques and so the use of artificial intelligence became prominent.

A hybrid power system consisting of fuel cells and solar PV is proposed. The controlled output of the fuel cell will compensate for the variations in the output of solar PV unit. The frequency of the hybrid system will be controlled by a suitable controller. The proposed hybrid system will be modelled and simulated. The proposed controller and optimization technique will stabilize the system frequency. Simulations and algorithms will be demonstrated using suitable tools to validate the design.

Keywords: —Photovoltaic cells, Hybrid power systems, Energy Storage systems, Fuel cell, Load Frequency control.

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1. Introduction

Power Generation from conventional energy resources like coal, diesel and nuclear, is economical and reliable but on the other hand faces some serious environment issues. The resources itself are in the stage of extinction. There arises a strong need of renewable energy resources for power generation.

Distributed generation includes generation of electrical energy on small scale at a location close to the consumers. Different locations have different types of resources like solar, wind, small scale hydropower, biomass, ocean energy, fuel cell and even waste which can be used for generating electricity. Such sources can be used for distributed power generation. A distributed generation system can be small and feed a very small load like a single household or it can be big to feed a locality or a village. Distributed generated system can work in standalone mode where the power generated is supplied to the local load and also it can work in grid connected mode where the power generated can be supplied to the power utility. In most cases renewable energy is used in distributed generation which makes it environment friendly. As power is generated near the load, the cost of transmission as well as the power loss during transmission are minimized which makes distributed generation economically cheaper and more efficient. Efficiency can further be improved by using combined heat and power plant.

Fuel cells are like a continuous battery and can be used in a hybrid power system. Whether it be a internal combustion engine or a turbine powered generating unit, all are a source of carbon and greenhouse gas emissions and so needs to be replaced. Fuel cells does not emits any pollutants, gives higher efficiency and can be used for a wide range of applications from portable devices to high capacity power plants.

Solar energy is another such type of renewable energy resource which can be used for generating electricity either through photovoltaic (PV) cells or by solar thermal power generation. Solar PV is most easy to install and is gaining much popularity. But solar availability is not constant throughout the day; which causes variations in the solar PV generated output. This in turn causes serious system frequency stability issues. Solar PV system is never used alone; either storage devices or another source of generation are used alongwith solar PV system thereby making a hybrid power system.

Automatic generation control (AGC) becomes most important control system which maintains the system frequency at a nominal value (within acceptable limits) and maintains the correct amount

of power interchange between different power systems meanwhile maintaining each units generation at the most economical value. When load is shared by both the generating sources then generation control becomes more complicated. For detecting any change in load and the power generation, a control system (LFC) is needed which can stabilise the system frequency.

So as to maintain the system frequency within stable limits, various controllers are implemented. Proportional-Integral-Derivative controllers are used widely for load frequency control. They are having various advantages such as low cost, simple structure, provides good stability, rapid response and is stable. Although we need to tune it's parameters. Various optimization techniques are used for that like genetic algorithm (GA), particle swarm optimization (PSO), ant colony optimization, moth flame optimization, etc. Also other controllers are used like fuzzy logic controller (FL), artificial neural network (ANN), linear quadratic regulator controller, robust controller based H∞.

2. Literature Review

Veronica1 et al. in 2020 proposed a hybrid power system consisting of a wind turbine generator (WTG) combined with a diesel engine generator (DEG). Combination of the renewable WTG and non renewable (DEG) generating units makes the controlling of real power generation of the power system more effective. Proportional Integral (PI) controllers are used in this hybrid power system so as to minimise the frequency variations. For determining the parameters of the PI controller optimization techniques used were D-partition method and Ziegler-nichols method. It is seen that on implementing the D-partition method frequency deviation reduces and so does the settling time of the system.

Hasan et al. in 2013 proposed a hybrid power plant consisting of a wind power generating unit, a micro hydro generating unit and a diesel engine generating unit. Depending on the locations and the intermittency of wind power; wind and micro hydro power generations were combined with the conventional diesel generating unit. The proposed hybrid power system increases the reliability of the power system. The supplementary controller of the diesel generating unit minimized the variations in the system frequency caused either by the small real power load change or due to change in input wind power. An Adaptive Neuro Fuzzy Interface System (ANFIS) based neuro-fuzzy controller was designed individually for both the governor of the diesel engine generator which improved the governor performance and also for a blade pitch control in a wind side as a

supplement controller for pitch control. The system frequency variation was served as a feedback input on diesel generating unit, which further balanced the differences between the generated power and the load demand by adjusting the speed changer position.

Magdy et al. in 2018 introduced an energy storage systems (ESS) in the hybrid power system. The ESS used was superconducting magnetic energy storage (SMES). Surplus power generated by renewable energy source was ESS and during deficit that power was fed to the grid. The charging and discharging of SMES is very fast thereby giving power output and huge amount of power is immediately available for a shorter duration. With the increasing share of RES in the generating part, the frequency variations also increases, so the power system under consideration is having a high percentage of RES generation and load frequency controlling system alongwith SMES unit together stabilizing the system frequency with SMES also acted as a feedback controller.

Yang et al. in 2015 connected electric vehicle to a power system, and it's battery was used to store power. So the battery drew power and that power was used for driving the electric vehicle; also the power stored in the battery was pumped back to the power system when needed. As per statistical data private cars are parked for most of the time and in this duration they can be connected to the power system. With increasing numbers of electric vehicles, the storage available for the generated power is also increasing. This technology of using electric vehicles for storing electric energy is known as V2G (vehicle to grid) technology. These electric vehicles store the surplus power generated and also feed power to the grid when needed and thereby makes the generated power equal to the load and so eliminating the frequency deviations. The proposed hybrid power system consisted of a diesel engine generator, a wind turbine generator and electric vehicle (as energy storage system). Multivariable generalized predictive control (MGPC) based load frequency controlling was used and the control signal was generated in accordance with wind turbine generating unit's change or the load change and was fed to the diesel engine generating unit and the electric vehicle storage.

Lotfy et al. in 2018 proposed a hybrid power system consisting of wind turbine generator (WTG), photovoltaic generation (PV) Fuel cell (FC), battery energy storage (BESS), diesel engine generator (DEG) Flywheel (FW) and Electric vehicle (EV). Aqua electrolyser (AE) dissociates water into hydrogen and oxygen. Hydrogen evolved as due to electrolysis was collected in an hydrogen tank which was further used as fuel for FC. The error signal which was due to the disturbances in both the load and the renewable source generation had both high as well as low

frequency component. Fast discharging storage units BESS & FW were used to minimize fast varying components of generator side variations. Slow discharge units like FC, FW and DEG were used in controlling slowly varying components of generator side variations. Two proportional integral (PI) controllers were used in the power system. Each of the PI controller maintain the system frequency within acceptable limits and eliminate the a effects of the variation in generation (of renewable sources). Epsilon multi objective genetic algorithm (ε-MOGA) was used for the parameter optimization of the PI controllers.

Shankar et al. in 2016 proposed a two area hybrid power system. Control area 1 was connected through a tie line to another area 2. Area 1 is having three generating units, ie. reheat thermal turbines, hydro turbine & gas turbine power units. Area 1 was also having energy storage system (ESS) which feeds the integral (I) controller so as to compensate for the time lag and hence maintain the system frequency within acceptable limits. Redox flow battery (RFB) was used in energy storage system. The error signal serves as the input for the RFB. SSSC FACTS controller was used for inducing a voltage in quadrature with line current so as to control the reactive power and enhance power transmission through tie line. SSSC when kept in insulation in series with the tie line helped in balancing frequency. Higher and lower values of compensation required from SSSC can were obtained by controlling the triggering of power semiconductor switches in the SSSC. RFB eliminated the lag time hunting in the system caused by changes in load. Genetic algorithm (GA) was used for parameter optimization of the Integral controller.

Ferahtia et al. in 2020 proposed a hybrid power system based on Fuel Cell, Photovoltaic source and Supercapacitor. Including the supercapacitor fastened the response of the system in case of transient period. Implementing a PI controller in the system reduced the variations in the voltage at the bus bar and provided a constant power to the load.

3. Gap Identified

Considering the scenario of India, various government projects like the rural electrification and make in India campaign has increased the dema°nd of electricity. Also the government of India is highly focused on increasing the share of renewable sources in the power generation sector. India is having a good scope for fuel cells. Hydrogen is the most common input of fuel cells; hydrogen can also be produced from other gases like natural gas and landfill gas (Manwell, 2004). India is having a good amount of biomass which can be used for production of natural and landfill gas.

Electrolysis of water is another method of producing hydrogen from water. Fuel cells combined with wind and solar based hybrid power generation is very less researched in many countries. Another issue faced being the intermittent nature of solar and wind energy, the system frequency varies. The hybrid power plant designed must be maximizing the solar energy exploitation which can be achieved by maximum power point tracking. The previous researches involves the use of energy storage systems, which further increases the cost of power generation. Also the usage of artificial intelligence in load frequency control of renewable sources based power generation is limited and the use of advanced optimization algorithms like moth flame optimization and grey wolf optimization is not much used for optimizing the parameters of conventional PID controllers in the renewable energy power generation model.

4. Description of Broad Area

There are different types of fuel cells like: Proton Exchange Membrane Fuel Cell (PEMFC), Direct Methanol Fuel Cell (DMFC), Alkaline Fuel Cell (AFC), Phosporic Acid Fuel Cell (PAFC), Molten Carbonate Fuel Cell (MCFC), Solid Oxide Fuel Cell (SOFC), Reversible Fuel Cell (RFC), etc. Each type of fuel cell has different properties, advantages and disadvantages. Operating temperature of fuel cells varies from 60 °C for PEMFC to 650 °C for MCFC (Cassir et. al, 2013). Fuel cells have high efficiency of approximately 60% which can be further increased with cogeneration. The efficiency of fuel cells remains high irrespective of size which makes it suitable for smaller size highly efficient low cost power plant ranging from several hundred to low MW capacity plants. Smaller plants can be located in the consumer facility and they can also be used for cogeneration. Larger plants having capacity upto few MW are suitable for distributed generation. PC-25 developed by UTC Fuel Cells in 2002 was the first commercial fuel cell unit with rating 200 kW. Through a fuel processor, natural gas was converted into hydrogen rich fuel which was fed to the fuel cell. It was suitable for applications such as Uninterrupted power supply, independent power source and for cogeneration in various commercial and non-commercial buildings (Williams, 2004). A higher capacity 50 MW fuel cell power plant was installed by Hanwha Energy in South Korea in August 2020. Fuel used is hydrogen recycled from petrochemical manufacturing is used as the fuel (Stangarone, 2021). With the high operating range, fuel cells are suitable for rural sector.

As per the geographical location of India (20.5937° N, 78.9629° E), it receives a huge amount of

solar energy, much larger than other sources of energy. Most parts in India experience 250 to 300 sunny days in a year. About 5,000 trillion kWh per year energy is incident over India's land area with most parts receiving 4-7 kWh per sq. m per day. This huge amount of solar energy available can be exploited using solar photo voltaic (PV) systems. Installation of solar PV system is least time consuming and it's capacity can be increased easily as and when required. Although a small fraction of solar energy available can fulfill our energy demand, but it is diffused and so to capturing and utilizing is not that easy. Along with electricity generation, solar energy is a big source of passive energy which can be used for cooking, lighting, heating, etc. India is having area of 3.287 million km^2 out of which about 98610 km^2 is waste land. If solar PVs are installed on this waste land area then 748 GW power would be available. Government's National Solar Mission (NSM) aims to install 100 GW grid-connected solar power plants by the year 2022 out of which 40.1 GW is currently installed. Solar tariff in India has become comparable with grid supply. Along with wasteland, rooftop installation of solar PV units is a very feasible option in the rural as well as urban areas. With 110 square foot roof top area of gives feasibility of a 1KW plant producing about 3.8 kWh per day. (Ministry of New and Renewable Energy- Solar photovoltaic installation, 2021)

Load connected to a power system is never stable. With a change in load, the active power and correspondingly the system frequency also changes. To prevent any disturbance in the system, the active power needs to be balanced and so the frequency.

Many residential and commercial and even rural areas are having scope of PV and fuel cell installations. Solar energy can be concentrated for heating and reaching the working temperature of the fuel cells. This heat can be used further for other applications thereby increasing the efficiency of the system. Although the initial cost is high but the recovery period is less like 3-4 years. For promotion of such environmental friendly and carbon neutral methods of power generation, government is offering subsidies and easy loans. Such hybrid power systems if used in grid connected will reduce the load on the power utilities. The issue of the diversification of solar energy needs to be researched upon by providing ample amount of alternate source either by another power generation source or an energy storage system. Correspondingly the controller needs to be optimally maintain the system frequency by supplying the required power from the alternate source when solar availability reduces and vice versa.

5. Problem Identification

Previous Research work has explained various optimization techniques for Hybrid Power Systems. The previous methods used to optimize Hybrid Power Systems are including a renewable source based power generating unit alongwith a conventional source based power generating unit or uses an energy storage system. Weather conditions and solar irradiance reduces the system efficiency which has to be maximized and transient response of the system needs to be controlled so as to make the system stable.

Intention here is to develop a hybrid power system where generation is to minimize the power generation cost, improving the efficiency and the stability by monitoring the parameters which changes with environmental conditions and to choose economical methods of storing the energy. Use of artificial intelligence techniques for integration of the system and optimization of the controller to maintain system frequency.

6. Objectives of Research

For the achievement of the proposed research work, objectives are outlined below:

1. To review different renewable sources based hybrid power generation plants.
2. Perform modeling and simulation of solar PV system.
3. Perform modeling and simulation of fuel cell system.
4. To develop PV and Fuel cell hybrid model and maintain power quality under different loading conditions with variable solar irradiance considering the fuel cell state
5. To provide power management strategy with arranged power sharing between the sources.

7. Methodology to be adopted

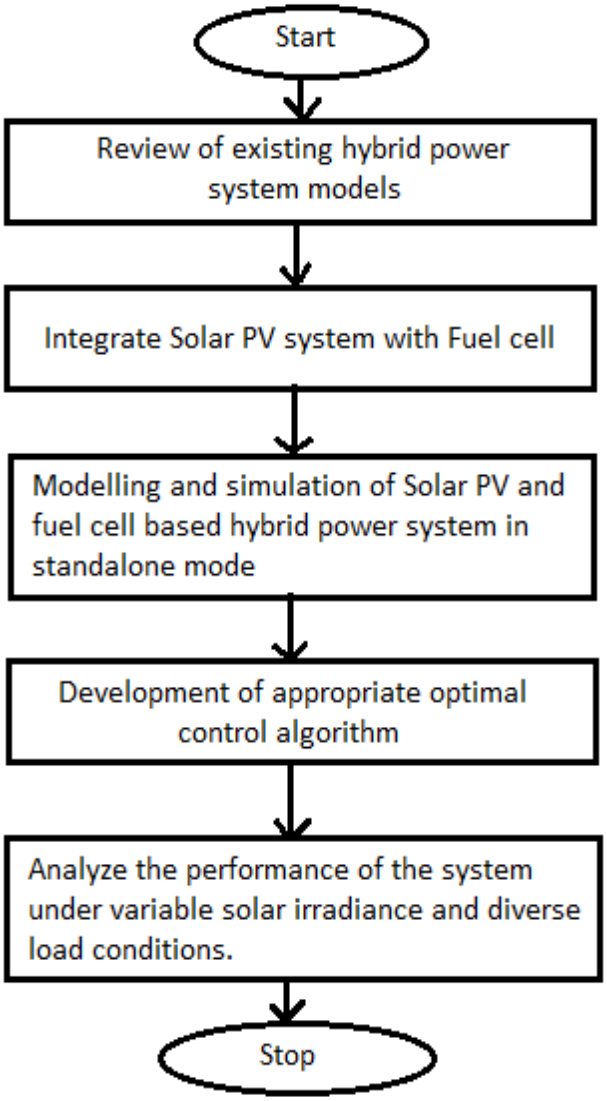
Start
Review of existing hybrid power system models
Integrate Solar PV system with Fuel cell
Modelling and simulation of Solar PV and fuel cell based hybrid power system in standalone mode
Development of appropriate optimal control algorithm
Analyze the performance of the system under variable solar irradiance and diverse load conditions.
Stop

Fig. 1: Flowchart for methodology to be adopted

The research will proceed in following steps:

1. Different types of power systems will be studied in detail including the different generating modules and the controllers.
2. Collect solar irradiance data corresponding to a geographical location using PVsyst. Prepare solar PV and Fuel cell based model for the location and integrate it.
3. Perform modeling and simulation of the hybrid power system in standalone mode.
4. Develop an optimal control algorithm for the hybrid power system.
5. Analyze the performance of the system under different loading conditions and variable solar availability.

8. Expected Outcome of the Research

There are valuable outcomes of this research work could make to the engineering area:

1. The proposed power system model will provide a feasible solution for providing continuous power supply.
2. The proposed model will reduce the losses during transmission of electric power and thereby will be more efficient and economically viable.
3. The proposed model will reduce the dependencies on fossil fuels for power generation and eliminate the adverse effects on environment.

9. Proposed Time Frame

Time Frame	July 19- June 20	July -June 21	July- Dec 21	Jan- June 22	July-Dec 22
Course Work					
Extensive Literature Survey					
Problem Statement					
Modelling of hybrid power system					
Simulation of PV Power Plant					
Simulation of fuel cell unit					
Develop and Analyze system in Standalone and Grid connected mode					
Publications related to the research work					
Detail Writing and submission report					

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